A reduction in the void ratio of the unconsolidated deposits, due to overburden pressures, produced a silt and clay bridge of sufficient shear strength to withstand nominal short-term dynamic loading. The bridge over the chimneys was inherently unstable and susceptible to shear failure. The probability of shear failure would be substantially increased if any of the following conditions occurred:

1. short-term de-watering of the residuum above bedrock;
2. excessive dynamic short-term loading;
3. abnormally high short-term subsurface water levels followed by rapid lowering of ground-water levels; and
4. modification by man, either excavating or filling the doline.

The mechanism for collapse of the Port Royal stock pond appears to be primarily one of abnormal short-term dynamic loading in combination with the removal of 2 to 4 ft of partially consolidated bridge material over the solution chimneys. Doline modification not only produced further local compaction and short-term vibration of the remaining bridge material by the bulldozer, but a decrease in the thickness of the bridge. During the period required to fill the pond, hydrostatic pressure on the soil bridge increased. The stock pond collapsed when the overburden stresses acting perpendicular to the soil bridge exceeded the shear strength of the bridge material. An estimate of the overburden stresses acting perpendicular to the soil bridge prior to failure are computed below.

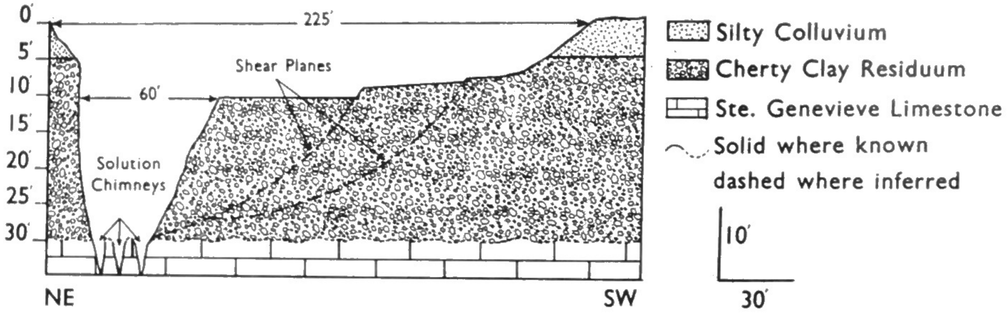

FIG. 1: *Northeast-Southwest Cross Section of the Port Royal, Tennessee, Doline Collapse (exaggerated 3X).*

In order to estimate the magnitude of stress on the soil bridge, several parameters must be known or estimated. The weight of water (W_w) and the weight of the soil mass (W_s) per unit volume (V) are related by a rather standard equation in soil mechanics (Means, 1963).

$$\gamma_m = (W_w + W_s) \ / \ V \qquad (1)$$

Where γ_m = average soil mass density of a water-clay system. The estimation of W_w requires knowing the average soil mass density and the field moisture content W_n. In a water-clay system, with a field moisture of 25%, a γ_m of 110 lb/ft^3 is a typical value. The field moisture value of 25% is an average based on work done in the general area by Royster (1967). Knowing that $W_w = 0.25\ W_s$ and substituting this expression in eqn.1 and solving for W_s

$$110 \text{ lb/ft}^3 = (0.25\ W_s + W_s) / (1 \text{ ft}^3)$$

$$W_s = 88 \text{ lb/ft}^3$$

The weight of the soil per unit volume is then simply the difference between γ_m and W_s or $W_w = 22$ lb/ft^3. The volume occupied by both the soil (V_s) and the water (V_w) can then be determined using the following relationship (Means, 1963):

$$V_s = W_s / (\gamma_w \ d_s) \qquad (2)$$

Where: γ_w = unit weight of water; d_s = specific gravity of the substance

Then: $V_s = 88 \text{ lb} / (62.4 \text{ lb/ft}^3 \times 2.65)$

Therefore: $V_s = 0.532 \text{ ft}^3$

V_w is calculated using eqn. 2 above after substituting W_w for W_s

$$V_w = 22 \text{ lb} / (62.4 \text{ lb/ft}^3 \times 1.00)$$

Therefore: $V_w = 0.353 \text{ ft}^3$

Given a unit volume of 1 ft^3, the volume of voids in the water-clay system becomes the difference of the unit volume and the volume occupied by the water. The soil mass therefore has 0.468 ft^3 of void space of which 0.353 ft^3 is filled by water.

The problem of estimating the overburden pressure on the soil bridge (T) immediately prior to the collapse involves summing:

1. the overburden pressure due to the soil mass above the bridge; and
2. the hydrostatic pressure produced by the water-filled pond.

This is easily accomplished using a rather conventional expression (Means, 1963):

$$T = h_w \gamma_w + h_r \gamma_m \qquad (3)$$

Where h_w and h_r are the depth of the water and the thickness of the soil bridge, respectively. γ_w and γ_m represent the unit weight of water and the average soil density of the water-clay system, respectively. The total overburden stress on the soil bridge T (lbs/ft^2) becomes

$$T = 8 \text{ ft } (62.4 \text{ lb/ft}^3) + 22 \text{ ft } (110 \text{ lb/ft}^3)$$

The overburden pressure on the bridge immediately before the collapse is estimated to have been approximately 2920 lb/ft^2 (1.46 tons/ft^2).

The failure of the stock pond and subsequent infilling and removal of residuum and colluvium (via the solution chimneys) produced an over-steepened face along the southwest edge of the void. A slump developed in the remaining undisturbed pond bottom (Figure 2). The slump is a post-collapse feature produced in response to an oversteepened (55°) slope-face experiencing shear failure due to the loss of lateral support. Two concave shear planes appear on the undisturbed portion of the pond bottom approximately 65 ft and 100 ft southwest of the slump face. Approximately 6 in. of rotational movement had already occurred along the shear plane nearest the face before this study began. Rotational movement along the second concave failure plane averaged considerably less than 6 in. Since the measurements were made in August 1973 and again in September 1974, little additional movement has taken place. Accurate measurements, in September 1974, were precluded by the owner's efforts to repair the stock pond. Efforts to repair the stock pond by filling the void have been largely unsuccessful.

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EFFECT OF THE UNIVERSAL RADIATION FIELD ON HIGH ENERGY COSMIC NEUTRINOS

RONALD ELBERT MICKENS
Department of Physics
Fisk University
Nashville, Tennessee 37203

ABSTRACT

We calculate the interaction of high energy cosmic-ray neutrinos with the 3°K universal radiation field. In contrast to the situation with protons, electrons, and photons, no cut-off to the neutrino cosmic-ray energy spectrum should occur.

INTRODUCTION

The purpose of this paper is to calculate the effect of the 3°K blackbody radiation field (Penzias and Wilson, 1965) on high energy cosmic neutrinos.

Several authors have investigated the consequences of the existence of the 3°K thermal radiation. One consequence is to provide a source of X-rays and gamma-rays by inverse Compton interactions with high-energy cosmic-ray electrons, (Felton, 1965; Hoyle, 1965; and Gould, 1965). In addition, the interaction of the 3°K radiation with high-energy cosmic-ray photons makes the universe opaque to cosmic-ray photons with energy above 2×10^{14} ev, because the photon-photon interactions can lead to electron-positron pair creation and the cross section for this process is large (Gould, and Schreder, 1966; and Jelly, 1966). Hoyle (1965) was the first to consider the effect of the 3°K radiation on cosmic-ray protons. He concluded that the time scale for energy degradation is greater than the expansion time of the universe for all protons having energies less than 10^{21} ev. However, his results are in error in that he considered only the proton Compton scattering and did not take into account photo-pion production which has a much larger cross section. In independent calculations, Greisen (1966), and Zatsepin and Kuzmin (1966) showed that through photo-pion production the 3°K radiation would have a strong attenuating effect on cosmic-ray protons with energies exceeding 10^{20} ev. These photo-pion reactions can occur because the 3°K photons look like high-energy gamma-rays in the rest system of the protons. The mesons, resulting from the interaction, carry off a significant fraction of the energy of the cosmic-ray protons and therefore attenuate the proton spectrum. Later, Stecker (1968) made a detailed calculation of the lifetime and attenuation mean-free path of high-energy cosmic-ray protons against photo-meson production. His calculations utilized the results of the then recent laboratory studies of photo-meson production cross sections. He concluded that protons whose energies exceed 10^{20} ev will be attenuated if they originate beyond a distance of about 10Mpc.

CALCULATIONS

As stated earlier, the purpose of this paper is to calculate the interaction of high-energy cosmic neutrinos with the 3°K cosmic radiation field. In order to do this, we need an estimate of the neutrino-photon total cross section. This estimate may be gotten from the vector-meson-dominance model (VMD) (Feld, 1969), which gives us,

$$\sigma(\nu+\gamma) \cong a\sigma(\nu+\rho), \qquad (1)$$

where $\sigma(\nu+\gamma)$ and $\sigma(\nu+\rho)$ are the total cross sections for neutrino-photon and neutrino-proton scattering and a is the fine-structure constant (Feld, 1969). Scaling (dimensional analysis) allows us to calculate the neutrino-proton total cross section, (Lee, 1972),

$$\sigma(\nu+\rho) \cong G^2S, \qquad (2)$$

where G is the Fermi weak coupling constant. S is a relativistic energy variable and is given by the following expression,

$$S = 4E_\nu E_\gamma, \qquad (3)$$

where E_ν and E_γ are the energies of the neutrino and photon.

We shall consider the universal background radiation to be at a temperature of 3°K (Greisen, 1966). At this temperature the photon number density is $548/cm^3$ and the mean photon energy is 7.0×10^{-4} ev. These results and eqs. (1), (2) and (3) give the following value for the neutrino-photon total cross section,

$$\sigma(\nu+\gamma) \cong 5.64 \times 10^{-39}\ E_\nu cm^2, \qquad (4)$$

where E_ν, the energy of the neutrino, is now measured in units of GeV $= 10^9$ ev.

The cross section, given in eq. (4), is related to several other quantities of physical interest (Bond, Watson and Welch, 1965): (a) the mean free path, L; (b) the average time between collisions, T; and (c) the rate coefficient, R. For the problem under consideration in this paper these physical quantities take the following form,

$$L = (N\sigma)^{-1}, \qquad (5a)$$
$$T = L/C, \qquad (5b)$$
$$R = \sigma C, \qquad (5c)$$

where N is the number density of the photons and C is the speed of light. Using the cross section of eq: (4), we obtain,

$$L \cong 3.38 \times 10^{35}/E_\nu cm, \qquad (6)$$
$$T \cong 1.13 \times 10^{25}/E_\nu sec, \qquad (7)$$
$$R \cong 1.69 \times 10^{-28}E_\nu cm^3/sec. \qquad (8)$$

DISCUSSION

The radius of the universe is believed to be of the order of 10^{28} cm (Harwit, 1973). Thus, we learn from eq. (6) that the universe is essentially transparent to neutrinos having energies less than about 10^7 GeV. This conclusion is not changed if we consider the interaction of cosmic neutrinos with other cosmic particles, such as electrons, photons, protons and heavy nuclei, because even though their interaction cross sections are large, the number densities are smaller by a factor of at least 10^{-5} to 10^{-8} as compared with the background 3°K radiation (Rose, 1973). In addition, if the neutrinos have an energy spectrum that follows a power law, as is the case for other cosmic particles (Weekes, 1969), then we expect the flux of neutrinos with energies larger than 10^7 GeV to be extremely small.

Likewise, the average time between interactions (collisions) is of the order of 10^7 times the estimated lifetime of the universe for neutrinos having energies as large as 10^7 GeV. At the energy, the rate coefficient R is approximately $10^{-21}cm^3/sec$.

We therefore conclude that cosmic neutrinos do not interact in any significant manner with the 3°K background radiation and consequently, no cut-off is expected in the neutrino cosmic-ray energy spectrum.

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